Aquatic Life

Background and Objectives

Streams, lakes, and wetlands provide habitat for cold and warm water fish, amphibians, and the species on which they depend. The Aquatic Life module provides a procedure for evaluating the needs of valued aquatic species and the condition of stream, lake, and wetland habitats. In this module, the term valued aquatic species refers to a single species, several species, or a functional group or guild of species that were identified for assessment during Scoping. The assessment is designed to determine how the flows of water, heat, pollutants, and other stream inputs are affecting the habitat and other needs of valued species.

For a Level 1 assessment the analyst collects and summarizes existing information on the population status, distribution, and ecological needs of the species. This information is then used to develop working hypotheses regarding how the species and habitat in the watershed have been impacted. Using existing habitat data, habitat in the watershed is evaluated based on the species' ecological needs. The results of the habitat evaluation are used to support or disprove the working hypotheses or to identify the need for further data collection and assessment.

The module also provides information on methodologies that can be used for a Level 2 assessment. While Level 1 assessment relies primarily on existing information, Level 2 assessment is used when more extensive data collection and analyses are needed.

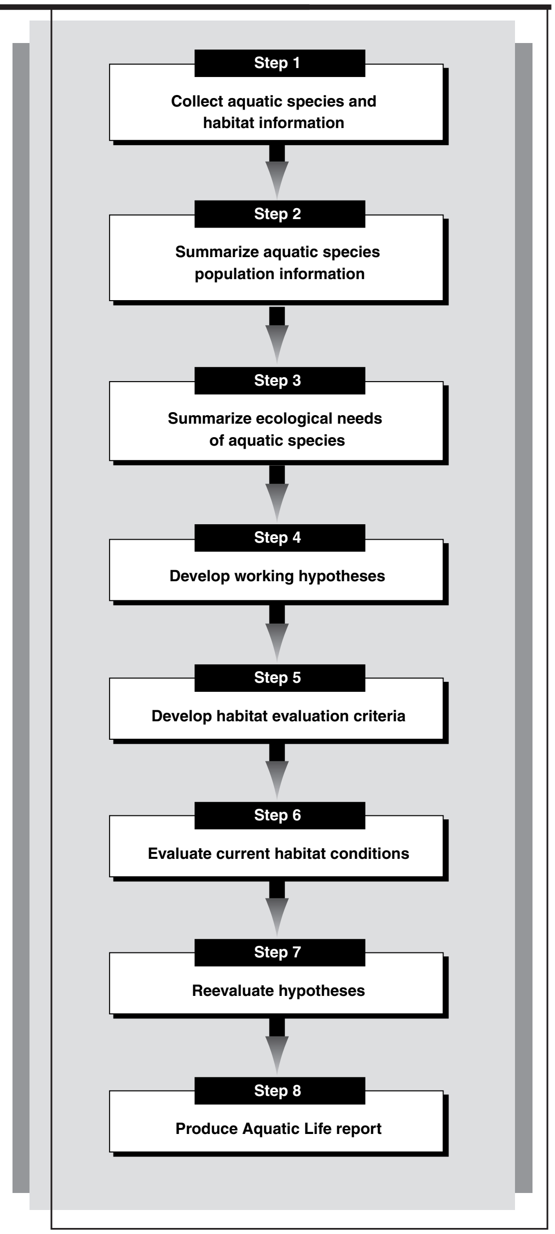
Aquatic Life Module Reference Table

Critical Questions	Information Requirements	Level 1 Methods/Tools*	Level 2 Methods/Tools*
AL1: What are the valued aquatic species that are present in the watershed?	• Information on species and distribution	• Consult watershed and species experts • Evaluate existing information • Investigate watershed history	
AL2: What are the distribution, relative abundance, population status, and population trends of the aquatic species?	• Historical and current population estimates and species distribution information	• Consult management agencies, watershed experts, and species experts • Collect existing regional information	• Collect watershed-specific information • Population modeling • Bioassessment methods
AL3: What are the requirements of various life history stages of the aquatic species?	• Scientific literature • Regional information and regional models	• Identify the habitat requirements (by life stage, season, etc.) • Consult with species experts	• Instream Flow Incremental Methodology or habitat suitability indices analysis • Suitability criteria development • Regional models
AL4: What are the habitat conditions for the aquatic species?	• Scientific literature • Existing habitat survey information	• Develop descriptions of current habitat conditions • Develop and apply evaluation criteria	• Collect watershed-specific information • Modeling
AL5: What connections can be made between past and present human activities and current habitat conditions?	• Historical information on watershed conditions • Current information on watershed conditions • Aerial photos	• Summarize watershed history • Consult watershed experts • Analyze aerial photos • Evaluate existing habitat survey information	• Modeling • Expert system

* Overlap exists between Level 1 and Level 2 methods. Often, the difference consists of the level of effort expected or whether existing information is used or the collection of new information is needed. Most Level 2 methods incorporate actions that are identified here as Level 1 methods (for example, consulting watershed or species experts).

Level 1 Assessment

Step Chart



Data Requirements

- Map of streams, lakes, and wetlands within the watershed.
- Land use map or recent aerial photos.
- Information on the population status, population trends, and distribution of the aquatic species. Sources for this information include agency records, species distribution maps, basin management plans, stock management plans, historical and current population assessments, and endangered species assessments and descriptions.
- Information on aquatic habitat conditions from state and federal agency records and existing habitat surveys.
- Information on dams, diversions, stream channelization, and alteration of lakes or wetlands. Much of this information may be historical.
- Information on existing or proposed listings under the ESA or under state endangered species laws.
- Professional opinions and information from resource professionals with expertise in the region, the watershed, or the aquatic species.
- Scientific literature on species' ecological needs.

Products

- Form AL1. Summary of hypotheses
- Map AL1. Aquatic species distribution
- Map AL2. Aquatic habitat distribution
- Map AL3. Aquatic habitat conditions
- Aquatic Life report

Procedure

Step 1. Collect aquatic species and habitat information

Collect available historical and current information on the valued species from federal, tribal, state, and local agencies and other community members. The information requirements are summarized in the Data Requirements section, above. Tracking down available information can be a time-consuming part of the process. Information gathering should also include interviews with agency biologists and any other individuals with expertise in either the assessment area or the aquatic species.

Step 2. Summarize aquatic species population information

Summarize the information from Step 1 focusing on the population status of the aquatic species and its distribution. Also summarize any available information about trends in population or distribution. The amount of detail for each of these topics may vary. Population information may be available only for an area larger than the watershed in question (e.g., a river basin or multi-state area) or may be very detailed (e.g., years of creel census information for a particular lake). Information may also be anecdotal (e.g., great declines in the range of a given species over the last 150 years). It may be that consulting watershed experts will yield the best information available.

At this point it may be useful to create Map AL1, the distribution map for the aquatic species under study. It may also assist other analysts to have this map.

Step 3. Summarize ecological needs of aquatic species

Using information that was gathered in Step 1, summarize descriptively or in a table the important life history patterns of the aquatic species and the species' ecological needs during each life stage (Box 1). This information, together with the distribution information, will help in determining the areas of the watershed that are important for different life history requirements or times of year. The information on life history requirements will also contribute to the development of hypotheses and habitat evaluation criteria. Examples of life stages include spawning, incubation, rearing, adult, and in- and out-migration. Requirements should be represented by factors that are measurable (e.g., water temperature) rather than those that, while important, are less likely to be measurable (e.g., genetic diversity).

Box 1. Life history preferences for stream-resident brook trout (*Salvelinus fontinalis*)

Life stage	Habitat preferences	Timing
Spawning	0.1 - 3" gravel, redd sizes < 2 ft^2	September - November
Incubation	No flood flows (causes redd scouring) or fine sediment inputs (smothers eggs)	Winter
Winter habitat	Pools with cover, interstitial spaces in cobble/gravel substrates	Water temperatures < 4°C
Summer habitat	Water temperatures 10°C - 19°C, adequate food (primarily insects, some fish), escape cover	Water temperatures > 4°C

Meehan (1991), Stoltz and Schnell (1991)

Step 4. Develop working hypotheses

Summarize important historical events and specific situations of concern

Using historical information and management plans, summarize past events and current situations in the watershed that are likely to have had an impact on either the population of the aquatic species or on habitat conditions. Summaries can be in text or table format. Following are examples of events or situations that could affect species or habitats:

- Historical presence or absence of a species (such as beaver) in a watershed.
- Historical introduction of an exotic species and subsequent interactions between native and introduced species.
- Past management actions such as hatchery operations or stocking programs.
- Disturbance events such as land clearing, dam construction, alteration of lakes or wetlands, floods, or fires that may have contributed to current habitat conditions.

Also consider situations such as changes in inputs of heat (e.g., loss of stream shading), sediment (e.g., landslides), streamflow (e.g., dams or diversions), and riparian conditions (e.g., grazing, land clearing). Consultation with other analysts at this stage may be very useful.

Channel
Hydrology
Vegetation
Water Quality
Historical
Conditions

Develop working hypotheses about impacts on aquatic species and habitats

Using the information collected and summarized in the previous steps, develop working hypotheses about cause-and-effect relationships between historical actions or current situations, a change in inputs to the aquatic system, and potential impacts on the aquatic species or its habitat.

Channel
Vegetation
Water Quality

It is not expected that enough information will be available to allow statistical testing of hypotheses in the scientific sense. Rather, the process of developing hypotheses is used to focus the assessment process and facilitate discussions. Communication among the Aquatic Life, Channel, Vegetation, and Water Quality analysts is essential to incorporate findings collected for one module into the assessment of another (e.g., water quality information as a habitat parameter), to identify data gaps, and to refine hypotheses.

A suggested format for summarizing working hypotheses is provided as Form AL1. Examples of general hypotheses are provided in Figure 1; the analyst should be able to generate more specific hypotheses than those shown.

Step 5. Develop habitat evaluation criteria

Generate a table of proposed habitat evaluation criteria based on the life history requirements of the aquatic species. Because of the importance of conclusions that will be developed using the criteria, community members and watershed experts should participate in criteria development whenever possible. This will provide a chance for feedback on variables used and the critical values selected.

Habitat evaluation criteria are defined in this module as characteristics of the environment in which an organism lives that can serve as effective indices of habitat condition and indicators of human-caused change. Criteria should be quantitative if possible. General categories of habitat criteria include the following:

- Floodplain characteristics.
- Riparian characteristics.
- Streambank characteristics.
- Stream channel, lake, and wetland characteristics.
- Streambed substrates.
- In-stream wood debris.
- Habitat quantity.
- Water quantity and quality.

Figure 1. Sample Form AL1. Summary of hypotheses

Species	Sub-basin	Description	Hypothesis	Source (include watershed expert as appropriate)
Stream-dwelling fish or amphibians	Beaver River	Beavers were common in the watershed prior to settlement and are uncommon now.	Pool, backwater, and wetland habitats formerly created and maintained by beavers may be less common now than they were in the past. This may have had the following impacts on the aquatic species…(*depending on the species preference for or dependence on these habitats*)	Historical records
Stream-dwelling fish or amphibians	Trout Creek	A severe fire burned the sub-basin in 1977.	Sediment or wood debris may have entered the stream channel, increasing sediment load and changing channel conditions. This may have had the following impacts on the aquatic species…(*depending on the species preference for or dependence on the channel conditions that result from these inputs*)	Agency records
Stream-dwelling fish or amphibians	Prairie Creek	Riparian trees were removed along the mainstem (1960-1975); current riparian vegetation is pasture grasses.	Changes in the riparian vegetation may have caused water temperature changes, changes in in-stream habitat conditions, or stream channel shifts. This may have had the following impacts on the aquatic species…(*depending on the species water temperature preferences or tolerances and habitat requirements*)	Aerial photos
A native trout	Deer Creek	Stocking of brook trout was widespread in the late 19th and early 20th centuries. Brook trout are established and will displace native trout.	The distribution of native trout may cover a smaller area now. This may have had the following impacts on the aquatic species… *(impacts could include population numbers, breeding opportunities, higher fishing pressure, etc.)*	Historical records
Brook trout	Spring Creek	Past management has relied on hatchery stocking. Current goals protect naturally spawning populations.	Because the management goal now supports natural spawning, the condition of the spawning areas may be critical for maintaining population numbers. Stream survey information indicates the following about conditions of spawning habitat…This may have had the following impacts on the aquatic species…(*depending on the species preference for or dependence on these conditions*)	Basin management plan

Identify regional criteria or develop literature-based criteria

For some species, appropriate habitat criteria and associated survey methods may already have been developed by management agencies. If regionally appropriate habitat evaluation criteria cannot be located for the aquatic species, criteria should be developed based on scientific literature and consultation with regional managers and biologists (Box 2). Interviews with watershed or species experts will provide valuable information.

Box 2. Guidance for developing habitat evaluation criteria

Bovee (1986) presents an excellent discussion of methods to develop habitat suitability criteria using watershed experts' opinions and scientific literature for situations in which collection of additional field data is not possible.

Box 3. Sources of habitat suitability models

Information on habitat suitability models can be obtained from regional offices of the USGS Biological Resources Division, particularly the Midcontinent Ecological Science Center, Fort Collins, Colorado (**www.mesc.usgs.gov**). The regional office in Lafayette, Louisiana (National Wetlands Research Center) may also have some documents available online (**www.nwrc.gov**).

Habitat criteria have been summarized for many species by the USFWS and the USGS Biological Resources Division based on investigations presented in the scientific literature (Box 3). These documents can suggest both appropriate criteria for consideration and a starting point for determining regionally appropriate values and ratings in discussion with watershed experts.

The example provided in Box 4 illustrates how habitat evaluation criteria can be developed based on scientific literature. Both critical thinking and common sense will be

Box 4. Development of habitat evaluation criteria based on scientific literature

Stuber et al. (1982) provide the following information on habitat conditions for largemouth bass (*Micropterus salmoides*) in rivers.

Life stage	Parameter	Good habitat conditions	Moderate habitat conditions*	Poor habitat conditions
Adult, juvenile, fry	Dissolved oxygen	> 8 mg/L	4 - 8 mg/L	< 4 mg/L
Adult, juvenile	Turbidity (suspended solids)	< 25 ppm	25 - 100 ppm	> 100 ppm
Adult, juvenile	Percentage pool habitat	> 60%		< 20%
Adult, juvenile	Percentage cover in pools	40 - 60%		
Adult, juvenile	Summer water temperature	24 - 30°C		< 15°C and > 36°C
Incubation	Water temperature	13 - 26°C		< 10°C and > 30°C
Fry	Water temperature	27 - 30°C		< 15°C and > 32°C
All	Salinity	< 1.66 ppt		> 4 ppt

* Moderate values are listed here if provided by Stuber et al. (1982).

Using the habitat conditions table for largemouth bass, habitat evaluation criteria could be developed for discussion with watershed experts. For example, dissolved oxygen criteria could be developed fairly simply. Levels greater than 8 mg/L could be rated "good," levels between 4 and 8 mg/L "moderate," and levels less than 4 mg/L "poor." For two other parameters, percentage pool habitat and summer water temperature, the "good" and "poor" ranges could be easily defined, but the question of how to assign a "moderate" rating might require more discussion. A "moderate" rating for percentage pool habitat could be assigned to the 30 - 50% range, and a "moderate" rating for summer water temperatures could be assigned to the 15.5 - 23.5°C range (assuming typical summer water temperatures are not less than 15°C).

necessary during this process. The goal is to identify a small number of appropriate criteria for each life stage of the aquatic species. Too many criteria can confuse the assessment. Focus should remain on those criteria that watershed experts agree are important to specific life stages and for which information has been collected. Criteria should also be measurable to allow comparison among sub-basins (e.g., stream shading and average tree height would be more useful than would a general description of riparian function). The criteria should help to illustrate where land use and human interaction with the landscape have the potential to change habitat conditions or alter population status.

Box 5. Development of human disturbance criteria

In a watershed with a mix of agricultural, urban, and suburban land uses, the identified issues are delivery of sediment and increased runoff to the stream during winter storms and fragmentation of the riparian corridor by roads, pipelines, and powerlines. Aerial photos can be used to make a count of road stream crossings per mile, which will indicate the number of delivery points for sediment and runoff and the relative amount of disturbance in the riparian corridor. Specific criteria for evaluating the level of human disturbance can be developed by comparing the number of road stream crossings per mile with regional values or by making comparisons across sub-basins or land use categories

May et al. (1997)

Develop human disturbance criteria

In addition to the evaluation criteria for specific habitat conditions, it might be appropriate to use an index of human disturbance, such as road density or percentage impervious surface (Box 5).

Step 6. Evaluate current habitat conditions

Use the information collected in Step 1 and the criteria developed in Step 5 to evaluate the current habitat conditions in the watershed. For each stream reach, lake, wetland, or sub-basin for which information is available, habitat is evaluated for the species or life stage that occurs there. The evaluation can also group species as appropriate or analyze groups of stream reaches, lakes, or wetlands where a particular species or life stage is important (e.g., spawning areas). In addition, the question of access into and out of particular habitats should be evaluated as necessary (considering both in- and out-migration, as appropriate). The analyst should focus both on typical habitats and habitats of special concern. Describing overall conditions is as important as, or more important than, describing unique or uncommon situations.

Compile a summary of available data on habitat conditions and apply the habitat evaluation criteria. An example of a format that could be used to summarize data is provided in Figure 2.

Figure 2. Sample habitat data summary form

Reach ID	Distance sampled	Pool Characteristics: Percent pool habitat	Rating	Percent cover in pools	Rating	Substrate Characteristics: Dominant substrate	Rating for spawning/ adult habitat	Sub- dominant substrate	Rating for spawning/ adult habitat

Water Quality Sample ID	Reach ID where sample was taken	Water Quality Characteristics: Dissolved oxygen (mg/L), Rating	Turbidity (NTU), Rating	Salinity (ppt), Rating	Additional parameter, Rating	Water Temperature Characteristics: Summer water temperatures (°C) (mean, range)	Rating	Incubation period water temperatures (°C)(mean, range)	Rating

Several criteria for a particular stream reach might fall into the "moderate" category. While it may be fairly straightforward to look at the criteria in the "poor" category and hypothesize connections between human-caused inputs and stream processes, the meaning of the "moderate" ratings can be less clear. Values that fall into a moderate range may indicate that conditions are changing from poor to good or from good to poor. The analyst can look for supporting evidence from other parameters in similar categories, such as other indicators of riparian condition or of in-stream habitat quality.

There may be situations in which only general information, not specific data, is available for a parameter considered important by the analyst or the watershed experts. In that situation, professional judgments can be made and indicated as such in the report. In addition, data gaps that were identified should be noted.

Habitat information should be evaluated critically. Habitat surveys are a snapshot of dynamic aquatic and riparian systems. Data may have been inconsistently collected, and sampling protocols will tend to change over time. Also, data may not be summarized in a manner helpful to the analyst. For example, data collected between two access points may cover several channel types. Events occurring after a survey (e.g., a flood) may have left the habitat in a different condition than data indicate. Collaboration between analysts will be the best source of information to assess these situations.

Step 7. Reevaluate hypotheses

Using the results of the habitat evaluation, reevaluate the working hypotheses developed in Step 4 (Box 6). Determine whether the information collected on current habitat conditions supports the hypotheses or indicates that the hypotheses should be revised. Also identify any hypotheses for which further data collection or input from other analysts will be needed. The hypotheses will be discussed with the other analysts during Synthesis.

Box 6. Sample reevaluations of hypotheses using conclusions from habitat evaluation

Hypothetical example 1

Shading levels are good in three of five sub-basins in the Little Pine watershed. The hypothesis is that, for the other two sub-basins, summer water temperatures may be less than optimal and may be limiting fish population numbers. Comparing available water temperature data and habitat criteria, it appears that summer water temperatures are higher than preferable but not lethal in the two sub-basins. No fish population or distribution data were available. Given that the hypothesis cannot be proved or disproved with existing information, the analyst then states the suspected problem: Shading levels are less than optimal in the two sub-basins, with possible negative impacts to fish habitat or populations from high water temperatures. This would then generate the following question for other analysts during Synthesis: Are stream shading levels in the two sub-basins likely to be increasing, decreasing, or staying the same? What effects might this have on future water temperatures?

Hypothetical example 2

Bullfrogs, an introduced non-native species in the western United States, are now present throughout the Bull Run watershed. Because it is well known that bullfrogs are very successful predators on native frogs, the following hypothesis was developed: Native frogs are now rarer than in the past and may only exist above barriers to bullfrogs. Native frog distribution information for the watershed shows that native frogs are in fact rare, except in one stream system where bullfrogs have been excluded. The analyst then revises the hypothesis by adding the idea that the small stream system should be identified as refugia for the native frogs.

Step 8. Produce Aquatic Life report

Produce maps

At least two and possibly three maps will be generated from the assessment. Map AL1 will present species distribution. An option is to also present historical distribution if it will contribute to the Synthesis discussions.

Maps AL2 and AL3 will present habitat distribution and a summary of habitat conditions. The habitat distribution and condition information could also be combined on one map, depending on the amount of information to be presented. The information included on the maps will vary with the aquatic species, its specific habitat requirements, and the geomorphology of the watershed. Examples of information that could be presented include the following:

- Spawning habitat, rearing habitat, adult habitat, and juvenile habitat (there may be "important/primary" and "less important/secondary" categories).
- Critical habitat (e.g., location of refugia or the only occurrence of a habitat type in the watershed).
- "Important/primary" habitat that is in degraded condition or in very good condition.
- Areas where habitat is in "naturally poor" condition (e.g., due to geology or soils).
- Areas where in- or out-migration is blocked.
- Dams, diversions, or irrigation withdrawals.
- Other topics of concern identified by the analyst (e.g., water quality problems).

Not all topics on this list will necessarily be presented on all maps. Whether one or two maps are needed to present the summary of habitat condition will depend on the number of aquatic species and the complexity of the situation. Often cartographic requirements that limit the amount of information easily included on a single map will prevail. Maps can be separated by concerns for a particular species, concerns during a specific time of year (such as winter, summer, or spawning periods), or other appropriate concerns. It may be helpful to present the channel segmentation and classification on one of these maps to assist in the development of hypotheses regarding channel and habitat responses to inputs such as sediment, water, and vegetation.

◀ Channel

Produce report

Produce a report summarizing information gathered and evaluation results. Critical questions should be kept in mind while developing the report. The report should include the following elements:

- A description of the valued aquatic species, their population statuses and trends, and their current distribution.
- A table summarizing life history requirements, which will be helpful for other analysts during Synthesis.
- A description of the historical abundance of and use of the watershed by the aquatic species.
- A description of the habitat evaluation criteria and the sources and methods used to develop the criteria.
- A summary of current habitat conditions within the watershed. Descriptions can be separated based on channel type, species or life stage, or sub-basin.
- A discussion of the hypotheses developed and evaluated.
- Identification of data gaps.
- A summary of the level of confidence in the assessment and in the various conclusions that have been reached (Box 7).

The report could also identify areas that may be critical habitat for a particular life stage, reaches with water quality concerns, reaches of high-quality habitat or of degraded habitat, and obstructions and blockages to migratory species or life stages. Comparisons could also be made between current conditions and descriptions of reference conditions for the particular ecoregion, if they are available.

Box 7. Sample summaries of confidence in the assessment

> Confidence is high in amphibian distribution information in the wetlands of the Bog Creek sub-basin because of recent extensive baseline surveys.
>
> Confidence is low to moderate for assessment of habitat conditions for brook trout in the Big Pine Creek sub-basin. No habitat surveys have been performed, and the assessment was made using aerial photos.
>
> Confidence is low regarding issues about water temperature for small lakes in the Ruby Valley watershed. No water temperature data were available, although watershed experts expressed concern about the potential for high summer water temperatures.

Level 2 Assessment

This section presents a selection of Level 2 assessment tools for aquatic species and aquatic habitat. Some methods allow the analyst to study the species of concern (or group of species) directly by assessing population size or species associations. Others use a measure of habitat availability or quality to assess ecosystem health or impacts from land use. Other methods incorporate approaches from population modeling and ecosystem theory.

This list of methods is not exhaustive. The analyst will need to consult with experts to determine whether a particular method is appropriate for the area under analysis and the topic of investigation.

Some of the methods presented below are fairly simple, while others require more time and resources. The analyst should consider whether extensive analysis is warranted by the magnitude of the problem under study and is feasible with the resources and information available. It is possible that a simpler approach will generate results with sufficient confidence to develop conclusions and policy recommendations. It should also be recognized that the science of ecosystem analysis is evolving, and tools and methods are continually under development.

Use of Aquatic Habitat Models

Instream Flow Incremental Methodology (IFIM)

The IFIM was developed by the USFWS to allow predictions of habitat quantity and quality for various aquatic species in riverine environments (Bovee 1982). It was developed for use in water allocation negotiations and operation of controlled rivers. Modeling is based on a combination of hydraulic factors measured in the river and general habitat preferences of fish species and life stages.

The strength of this approach is that it allows a quantitative estimate of gains and losses in fish habitat as flows incrementally change. One difficulty is that it can be expensive to collect the physical measurements and fish observations needed to generate a good quality model.

Habitat Suitability Indices (HSI)

The USFWS has also developed a series of descriptive models called HSIs for many species, including many fish and other aquatic-dependent species. The HSIs are developed from research literature and expert reviews and are intended to aid in identifying important habitat variables. They are hypotheses of species-habitat relationships, and users are expected to recognize that the veracity of model predictions will vary between places and will depend on the extent of the database for individual variables (Stuber et al. 1982; Terrell et al. 1982). This assessment tool can also be used in a Level 1 assessment.

The strength of these models is that they provide a quantitative index of habitat quality. They also present good summaries of what is known about the habitat requirements and preferences of a particular species. The analyst can then compare this information with the specific situation under analysis, choose the factors that are important, and devise the appropriate analysis approach. HSIs are different from the "expert system" approach outlined below because they require a higher level of expertise.

Use of an Expert System

Expert systems are designed to allow a less-experienced analyst access to the thinking and experience of those with greater expertise on the topic under consideration. They can be a series of questions posed to a group of experts, a dichotomous key, or a computer program. The strength of this approach is that the experience of experts can be accessed in a structured format. One problem with this approach is that it lends itself to a "cookbook" analysis, which might neglect an important habitat situation that was not addressed.

An example of an expert system is presented in MacDonald et al. (1991). They present an expert system that, through a series of questions, allows the investigator to generate a list of physical and biological parameters to be used in the design of water quality monitoring to investigate impacts from land use practices. An example of a dichotomous key for determining limiting factors for coho salmon freshwater life stages is presented by Reeves et al. (1989). This approach relies on field data for habitat parameters as well as estimates of adult escapement needs (see limiting factors discussion in the "Use of an Ecosystem Approach" section, below).

Use of Bioassessment Methods

Bioassessment methods vary widely, although all generally use measures of population size or makeup (e.g., number of species) to assess ecosystem health and response to land use activities. Examples include a simple presence/absence study for a single species and investigations of predator-prey relationships or other trophic-level interactions (Hauer and Lambert 1996). Multi-species sampling for fish and macroinvertebrates is also used to develop comparisons of population or habitat conditions within regions (Plafkin et al. 1989, Karr 1991).

Strengths of this approach include the fact that the aquatic species itself—rather than an indicator such as habitat conditions or water quality—is under study. Also, regional values for fish and macroinvertebrate species assemblages have been generated for many states or ecoregions (e.g., Kerans and Karr 1994). Difficulties with this approach include potentially high costs in time and resources and difficulty in finding reference sites to define good habitat conditions with which to compare the area under study.

Use of Population Model Predictions

The topic of population modeling is too large to address in this module; however, existing information on population status and trends for the aquatic species of concern will always be useful to the analyst. In addition, incorporation of population model predictions may also be considered by the analyst. The analyst should be informed about model strengths and weaknesses as well as the limits of both the data used in model development and the range of model predictions.

Use of an Ecosystem Approach

Watershed analysis is itself an approach that takes an integrated view of ecosystem processes and biological responses. Scientists have developed other methods or approaches that incorporate aspects of watershed analysis, such as assessment of watershed processes, with approaches drawn from ecosystem theory. A recent example, presented by Lestelle et al. (1996), uses salmon as an indicator species for ecosystem health. Like watershed analysis, this type of method works to integrate watershed processes, population dynamics and the effect of management actions. Another ecosystem approach is a "limiting factor analysis," which attempts to identify which habitat component constrains or limits the size of a population. An example of a limiting factor analysis method is presented by Reeves et al. (1989) and discussed in the "Use of an Expert System" section, above. Like population modeling, the topic of integrating ecosystem approaches and watershed analysis is too large to address in the module.

A strength of an ecosystem approach is that it builds on past research and integrates many of the dynamic factors that limit populations. One difficulty with this type of approach is that information requirements and analysis may become very complex.

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Form AL1. Summary of hypotheses

Species	Sub-basin	Description	Hypothesis	Source (include watershed expert as appropriate)